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Cooperative Spectrum Sensing: Two-sample Kolmogorov-Smirnov Test under Rician Fading Channel

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Abstract: Signal detection performance in cognitive radio architecture is enhanced by the cooperation of sensing detectors if the fading and shadowing effects exist on the channel. A cooperative spectrum sensing technique in cognitive radio networks based on two-sample Kolmogorov-Smirnov test is proposed in this paper and proposed sensing scheme is examined under Rician fading channel. The performance of the algorithm is investigated on real communication environment and real data; results show that two-sample Kolmogorov-Smirnov test based sensing offers robust and superior performance under Rician fading channel with low signal-to-noise ratio (SNR) values.

Keywords: Cognitive radio, Cooperative spectrum sensing, Two-sample Kolmogorov-Smirnov test, Rician fading channel.

I. INTRODUCTION

Cognitive radio (CR) technology was first proposed [1] to manage the frequency allocation problems due to spectrum crowding by multiple wireless devices and has been considered as the potential solution to improve the spectrum efficiency by the radios acting as secondary users and having opportunist access to unoccupied frequency bands. CR technology offers spectrum sharing between licensed primary users (PUs) and unlicensed secondary users (SUs). A SU can use the spectrum only when the PUs are inactive and on the condition that when it does not cause harmful interference to PUs. To use the channel opportunistically, a SU first needs sensing the environment and finding the white spaces. If no PU is detected, the SU then changes its parameters to communicate on the channel. Once starting to use the channel, if a primary signal is sensed, the SU should vacate the channel immediately. Thus spectrum sensing is one of the fundamental issues of CR technology with fast and accurate signal detection.

A variety of spectrum sensing methods have been proposed such as energy detection, matched filter detection, cyclostationary feature detection, eigenvalue based detection and recently detection based on goodness of fit testing [2]- [15]. The detection performance of spectrum sensing algorithms significantly degrades due to destructive channel conditions such as fading and shadowing. Fortunately, performance degradation can be improved by the cooperative sensing among secondary users acting as sensing detectors [16, 17]. The main idea on cooperative sensing is to share the SUs individual sensing information by using the spatial diversity of local users and making a fused decision which is mostly more accurate than the individual decisions.

In this paper, we propose a new approach to the cooperative spectrum sensing problem named two-sample Kolmogorov-Smirnov (KS) goodness of fit (GoF) test and hard decision combining rule is performed at fusion center to make the final decision. We test the algorithm under a Rician fading channel. The novelty of this work is that some GoF tests used on spectrum sensing problem is reformulated to cooperative scheme and their performances are investigated under a fading channel.

The rest of the paper is organized as follows. In Section II, cooperative sensing basics and prior works are presented. Section III mentions GoF testing based sensing system models briefly and Section IV presents the Rician fading channel model. The proposed algortihm formulation is introduced in Section V and performance analysis and results are discussed in Section VI. Finally, the paper is concluded in Section VII.

II. COOPERATIVE SPECTRUM SENSING (CSS)

The cooperation strategies for spectrum sensing basically rely on information share/exchanges among users (or nodes). The shared/exchanged information can facilitate the detection of white spaces and increase the efficiency of the spectrum sensing.

Cooperative sensing strategies can be classified into three main categories: centralized, distributed, and relay-assisted which differ from each other by how cooperating users share/exchange the sensing data in the network [18-22]. This paper focuses on the centralized CSS where the information coming from all nodes is combined to make a final sensing decision.

The SUs called also as sensing nodes detect the primary signal's availability independently and the detection information is then sent to a common controller which is also a SU (sometimes named as a fusion center). The

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fusion center (or decision center) is responsible for the final decision whether the channel is available or not for SUs' transmissions.

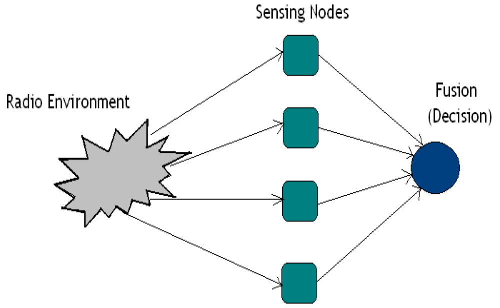

Fig. 1. Centralized cooperative sensing architecture

In centralized CSS schemes there are mainly three types of data fusion algorithms: Hard Decision Combining, Soft Decision Combining and Quantized Soft Decision Combining [16]. In hard decision fusion, CR nodes make a local decision and send the decision to the fusion center. On the other hand, CR nodes send the entire local sensing samples to the fusion center in the case of soft decision fusion. Quantized soft decision fusion rule relies on the quantization of local sensing samples and sending only the quantized data to the center for final decision. Several centralized CSS algorithms have been proposed in literature [23-30]. Although the soft combining strategies can have better sensing performances, they need more bits on reporting to the fusion center and thus they require more control channel bandwidth.

III. GOF TESTING BASED SPECTRUM SENSING

Spectrum sensing in a CR scheme is simply to determine the primary signal transmission in a channel. A Goodness of fit (GoF) test is a statistical way of describing how well it fits a set of observations or measurements. A GoF test enables to reach the discrepancy between observed/measured values and the values expected under the model. With the help of the calculation of the discrepancy between the empirical distribution of the measurements made locally at the sensing detector and the expected distribution, and making comparison between the discrepancy and the corresponding threshold, goodness of fit test can be used as a spectrum sensing method in CR architecture.

If there is no PU on the channel, i.e., no primary signal transmission, the measurements made locally at the sensing detector are a sequence of samples drawn independently from the noise distribution. On the contrary, in the case of existence of PU, measurements made will be different from the samples taken on the situation having only noise.

Therefore, to determine the existence of primary signals on the channel, a GoF testing can be formulated to check whether the measurements are drawn independently from the noise distribution.

IV. RICIAN FADING CHANNEL

The radio signals in some communication environments may be affected (mostly fade) by some natural and medium dependent factors such as the phenomena of path loss variance with distance, shadowing (or long-term fading), and multipath (or short-term) fading. Shadowing and multipath fading can be statistically described by fading models and several statistical distributions have been proposed for fading channels models including Rician/Rayleigh fading environment.

In Rayleigh fading model, the radio signal strength is supposed to vary randomly as it passed through the fading channel, i.e., the signal fades. If a dominant line of sight exists between the transmitter and receiver in a wireless medium, Rician fading models become more realistic. If a direct line of sight accompanied by the diffused signal component occurs in the medium, Rician fading model based on the Rician distribution has been proposed to be a more accurate model for the fading statistics [31]. A Rician fading channel can be described by two parameters V and S where V is the ratio between the power in the dominant direct path and the power in the scattered paths and S is the total power from all paths. In receiver part, the signal amplitude is now Rice distributed with the parameters α and β given below:

$$\alpha = \sqrt{\frac{V}{1+V}S} \tag{1}$$

$$\beta = \sqrt{\frac{S}{2(1+V)}} \tag{2}$$

The resulting probability density function (PDF) is then as follows:

$$f(x) = \frac{2(V+1)x}{S}\exp(-V - \frac{(V+1)x^2}{S})I_0(2\sqrt{\frac{V(V+1)}{S}}x) \tag{3}$$

where $I_0(.)$ is the 0th order modified Bessel function of the first kind.

V. TWO-SAMPLE KOLMOGOROV-SMIRNOV COOPERATIVE SENSING

In spectrum sensing algorithms, detecting the presence of primary signal is performed by taking some samples from the channel and then making a decision based on the algorithm analysis of the measured samples. The decisions are either the presence of the signal on the channel or no signal transmission. In cooperative sensing, more detectors are used to observe the transmission condition of the environment and to make collaborative decision.

Sensing algorithm based on only one sensor is presented first and cooperation algorithm is introduced next. Let the received samples observed by the sensing detector has the cumulative distribution function (CDF), $G(x)$. If there is no primary signal on the channel, observed samples CDF approaches to the noise distribution. In the presence of signal $G(x)$ will be different from the previous observations. Thus, a goodness of fit test for sensing detector is considered as making the decision between two hypotheses:

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$$H_0 : G(x) = F(x)$$
$$H_1 : G(x) \neq F(x) \quad (4)$$

where H_0 is the case where the received signal was drawn from a noise distribution, H_1 is the case where the transmission occurs on the channel, and $F(x)$ is the noise CDF. If the noisy channel model is added to the hypothetical test, the sensing problem is modified to make decision about two hypotheses:

$$H_0 : rs(t) = rn(t)$$
$$H_1 : rs(t) = s(t) + rn(t) \quad (5)$$

where again H_0 is the case that “channel is idle”, and H_1 is the case that “channel is busy” with $rs(t)$, the locally measured (or received) signal at the sensing detector; $s(t)$, the signal coming from the primary user signal; $rn(t)$ is the noise produced due to the existence of Rician fading channel. In the case of two-sample Kolmogorov-Smirnov testing, the statistic of two CDFs, denoted by $G_1(x)$ and $G_2(x)$, respectively, is defined as:

$$D_n(G_1, G_2) = \sup_x\{|G_1(x) - G_2(x)| : -\infty < x < \infty\}$$
(6)

where $G_1(x)$ and $G_2(x)$ are the CDFs of the first and second n-valued i.i.d. samples vectors. Thus, the statistic is determined by the largest absolute difference between two CDFs.

The statistic is evaluated practically by the calculation of the maximum vertical distance between $G_1(x)$ and $G_2(x)$ shown as the relation:

$$D^* = \max_i |G_1(x_i) - G_2(x_i)| \quad (7)$$

for a set of uniformly spaced sample points. The significance level α^* of the measured value D^* is formulated using the relation:

$$\alpha^* = P(D > D^*) = \Psi\left[(\sqrt{\tilde{N}} + 0.12 + \frac{0.11}{\sqrt{\tilde{N}}})D^*\right] \quad (8)$$

where

$$\Psi[x] = 2\sum_{m=1}^{\infty}(-1)^{m-1}e^{-2m^2x^2} \quad (9)$$

and

$$\tilde{N} = \frac{N_1 N_2}{N_1 + N_2} \quad (10)$$

The null hypothesis H_0 is accepted at a significance level α if $\alpha^* = P(D > D^*) \geq \alpha$ and rejected if α^* is less than α

Here the significance value α is an input of the test which is used to determine the probability of false alarm under the null hypothesis and formulated as:

$$\alpha = P(D > \zeta \mid H_0) \quad (11)$$

where ζ is a certain threshold value.

As a summary, the null hypothesis H_0 is accepted if the two-sample KS statistic is less than a predefined threshold, otherwise the hypothesis H_1 is accepted.

The proposed two-sample KS test-based cooperative spectrum sensing algorithm is carried out by the following steps:

1) The individual CR sensing detectors initially collect samples from the channel in “no signal transmission” case, i.e., noise samples.
2) The detectors then take samples from the channel for sensing the medium.
3) Each node then computes the CDFs of samples taken from StepII and StepIII, respectively and calculates the statistic value D^* and decides for a certain threshold value ζ for the intended false alarm probability.
4) Each sensing node makes its decision independently depending on the comparison of D^* and ζ values. The decision is either H_0 or H_1. If $D^* < \zeta$, the individual decision is H_0, i.e., “the channel is free”; otherwise the decision is H_1, i.e., “the channel is occupied by the primary user.
5) All CR nodes send their sensing information in the form of one-bit binary decisions (1 or 0) to the fusion center. OR-rule hard decision combining is performed at fusion center to make the final decision about the presence of primary user.

VI. PERFORMANCE EVALUATION

A. Cooperative Sensing Setup

For the performance analysis of the proposed method, we have used a test bed for implementing the cooperative sensing algorithm. The test bed includes GNU Radio platform which is an open source software toolkit providing a library of signal processing blocks for implementing the cognitive radio applications [32] and Universal Software Radio Peripheral 2 (USRP2) architecture which is a flexible low-cost cognitive radio hardware developed by Ettus Research [33]. USRP2 provides radio front-end functionalities with an FPGA and it allows making signal processing operations on a computer using GNU Radio and general purpose tasks including decimation, interpolation, digital up-down conversions in it.

We used real primary signals for the performance evaluation. Real signal samples are produced by a transmitter design which is a combination of GNU Radio and USRP2. The transmitter produced primary signal in the form of OFDM with 40 sub carriers at a centre frequency of 433 MHz. The CR sensing nodes are also formed using GNU Radio and USRP2. We have used 4

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CRs responsible for collecting data on the channel independently and making their own decisions. One of the sensing nodes also serves as fusion center and combines all the sensing information coming from the other CR nodes to make the final decision.

B. Results

We have used OFDM signals as a primary user transmission and we assumed that the transmitted signal is noise-free. To simulate the Rician fading channel, we have also produced and transmitted noisy signal samples based on Rician distribution.

Thus, when there is no primary signal transmission, the only signal on the channel is noise; and when the primary signal transmission exists on the channel, the sensed samples are the addition of primary signal and noise.

First, to determine the performances of the proposed method and existing methods without cooperative operation, we set the target probability of false alarm value to 0.1 (i.e., $P_f = 0.1$).

Table I shows probability of detection P_d values of proposed two-sample KS method (TSKS) and other methods (KS-one-sample KS, ED-Energy Detection, ST-Student's t-distribution, and AD-Anderson Darling based sensing) under Rician fading environment in a low SNR value (SNR=-8dB).

TABLE I Probability of detection P_d values of various sensing methods under Rician fading environment at $P_f = 0.1$ and $SNR = -8dB$.

Detector	TSKS	KS	ED	ST	AD
P_d	0.95	0.56	0.64	0.38	0.1

It is seen on Table I that the proposed method outperforms the existing methods. Since Anderson Darling based sensing has the worst performance under the Rician channel, the proposed two-sample KS method is compared with the other three ones.

Next, Table II shows the performance of hard decision rules (AND-rule, OR-rule, and MAJORITY-rule) as the collaborative probability of detection P_d and probability of false alarm P_f vs. average SNR based on the proposed method with 3 sensing nodes under Rician channel.

It is observed that OR-rule performs the best P_d ratios among the others whereas AND-rule has the least P_f values. Considering the optimal hard decision combining rule for higher P_d and allowable P_f range, OR-rule is seen to have better performance than AND-rule and MAJORITY-rule.

TABLE II Performance of hard decision combining rules via P_d and P_f vs. average SNR under Rician fading channel for N=3 CR users. Cooperative detection probabilities P_d of the proposed method and existing methods versus average SNR values with 4 collaborative CR users are depicted in Figure 2. OR combining rule is used at the fusion.

Average SNR	AND-rule P_d and P_f	OR-rule P_d and P_f	MAJORITY-rule P_d and P_f
-14 dB	0.904 0.012	0.988 0.07	0.968 0.04
-12 dB	0.91 0.01	0.985 0.1	0.96 0.032
-10 dB	0.93 0.004	0.981 0.05	0.97 0.028
-8 dB	0.946 0.008	0.99 0.05	0.972 0.016
-6 dB	0.96 0.064	10.01	10.08

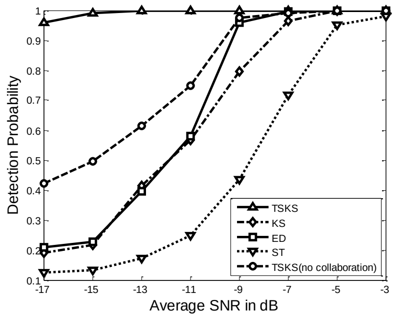

Fig. 2. Cooperative P_d values versus average SNR under Rician fading channel for N=4 CR users at $P_f = 0.1$

Figure 3 shows the Receiver Operating Characteristic (ROC) curves of the proposed cooperative two-sample KS method (TSKS) and former methods for a fixed value of SNR, -12dB, under Rician fading channel with OR-rule.

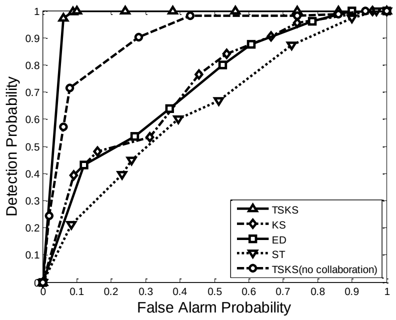

Fig. 3. ROC curves at SNR=-12dB with N=4

It is obviously observed from the figures 1 and 2 that two-sample KS method (no collaboration case) performance is superior to the performances of the cooperative KS, ED, and ST methods and proposed collaborative two-sample KS (TSKS) based sensing outperforms greatly and detection performance is doubled on the orders of -15 dB SNR values.

VII. CONCLUSION

In this paper, we derived two-sample KS test based cooperative spectrum sensing and investigated its performance in a Rician fading channel using the real data. The experimental results show that the proposed algorithm outperforms the existing methods and robust on the noisy

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environment. It is also seen that the sampling size of the two-sample KS test algorithm has low computational complexities with low SNR values. Performance analysis of the proposed method under different fading channels is the ongoing research efforts.

REFERENCES

[1]. J. Mitola and G. O. Maguire, "Cognitive radio: making software radios more personal," IEEE Personal Communications, vol. 6, no. 4, pp.13-18, August 1999.
[2]. A. Ghasemi and E. S. Sousa, "Spectrum sensing in cognitive radio networks: requirements, challenges and design trade-offs," IEEE Communications Magazine, vol. 46, no. 4, pp. 32–39, April 2008.
[3]. T. Yucek and H. Arslan, "A survey of spectrum sensing algorithms for cognitive radio applications," IEEE Communications Surveys and Tutorials, Vol. 11, No. 1, pp. 116–130, First Quarter 2009.
[4]. H.-S. Chen, W. Gao, and D. Daut, "Signature based spectrum sensing algorithms for IEEE 802.22 WRAN," in Proceedings IEEE International Conference on Communications (ICC'07), pp.6487–6492, June 2007.
[5]. J. Ma, G. Y. Li, and B. H. Juang, "Signal processing in cognitive radio," Proceedings of IEEE, vol. 97, no. 5, pp. 805–823, May 2009.
[6]. S. Kim, J. Lee, H. Wang, and D. Hong, "Sensing performance of energy detector with correlated multiple antennas," IEEE Signal Processing Letters, vol.16, no. 8, pp. 671–674, August 2009.
[7]. P. Sutton, K. Nolan, and L. Doyle, "Cyclostationary signatures in practical cognitive radio applications," IEEE Selected Areas in Communications, vol. 26, no. 1, pp. 13–24, January 2008.
[8]. S. Haykin, D. J. Thomson, and J. H. Reed, "Spectrum sensing for cognitive radio," Proceedings of IEEE, vol. 97, no. 5, pp. 849–877, May 2009.
[9]. Y. Zeng and Y.-C. Liang, "Eigenvalue-based spectrum sensing algorithms for cognitive radio," IEEE Transactions on Communications, vol. 57, no. 6, pp. 1784–1793, June 2009.
[10]. F. Penna, R. Garello, and M. A. Spirito, "Cooperative spectrum sensing based on the limiting eigenvalue ratio distribution in wishart matrices," IEEE Communications Letters, vol. 13, no. 7, pp. 507–509, July 2009.
[11]. H. Wang, G. Noh, D. Kim, S. Kim, and D. Hong, "Advanced Sensing Techniques of Energy Detection in Cognitive Radios," Journal of Communications and Networks, vol. 12, no. 1, pp. 19-29, February 2010.
[12]. H. Wang, E. Yang, Z. Zhao and W. Zhang, "Spectrum sensing in cognitive radio using goodness of fit testing," IEEE Transactions on Wireless Communications, vol. 8, no. 11, pp. 5427-5430, November 2009.
[13]. G. Zhang, X. Wang, Y. Liang, and J. Liu, "Fast and robust spectrum sensing via kolmogorov-smirnov test," IEEE Transactions on Wireless Communications, vol. 58, no. 12, pp. 3410-3416, December 2010.
[14]. L. Shen, H. Wang, W. Zhang, and Z. Zhao, "Blind spectrum sensing for cognitive radio channels with noise uncertainty," IEEE Transactions on Wireless Communications, vol. 10, no. 6, pp. 1721-1724, June 2011.
[15]. L. Lu, H. Wu, and S. S. Iyengar, "A novel robust detection algorithm for spectrum sensing," IEEE Journal on Selected Areas in Communications, vol. 29, no. 2, pp. 1-11, February 2011.
[16]. I. F. Akyildiz, B. F. Lo, and R. Balakrishnan, "Cooperative spectrum sensing in cognitive radio networks: a survey," Physical Communication, vol. 4, no. 1, pp. 40-62, March 2011.
[17]. K. B. Letaief and W. Zhang, "Cooperative communications for cognitive radio networks," Proceedings of IEEE, vol. 97, no. 5, pp. 878-893, May 2009.
[18]. J.Unnikrishnan and V.V.Veeravalli, "Cooperative sensing for primary detection in cognitive radio," IEEE Journal of Selected Topics in Signal Processing, vol. 2, no. 1, pp. 18–27, February 2008.
[19]. Z. Li, R. R. Yu, and M. Huang, "A cooperative spectrum sensing consensus scheme in cognitive radio," in Proceedings IEEE INFOCOM 2009, pp. 2546–2550, 2009.
[20]. G. Ganesan and Y.G. Li, "Cooperative spectrum sensing in cognitive radio—part I: two user networks," IEEE Transactions on Wireless Communications, vol. 6, no. 6, pp. 2204–2213, 2007.
[21]. G. Ganesan and Y.G. Li, "Cooperative spectrum sensing in cognitive radio—part II: multiuser networks," IEEE Transactions on Wireless Communications, vol. 6, no. 6, pp. 2214–2222, 2007.
[22]. W. Zhang and K. B. Letaief, "Cooperative spectrum sensing with transmit and relay diversity in cognitive radio networks," IEEE Transactions on Wireless Communications, vol. 7, no. 12, part. 1, pp. 4761–4766, 2008.
[23]. A. Ghasemi and E. S. Sousa, "Collaborative spectrum sensing for opportunistic access in fading environments," in Proceedings IEEE DySPAN 2005, pp. 131-136, 2005.
[24]. Y.-C. Liang, Y. Zeng, E. C. Y. Peh, and A. T. Hoang, "Sensing-throughput tradeoff for cognitive radio networks," IEEE Transactions on Wireless Communications, vol. 7, no. 4, pp. 1326–1337, April 2008.
[25]. W. Zhang, R. K. Mallik, and K. B. Letaief, "Optimization of cooperative spectrum sensing with energy detection in cognitive radio networks," IEEE Transactions on Wireless Communications, vol. 8, no. 12, pp. 5761–5766, December 2009.
[26]. W. Han, J. Li, Z. Tian, and Y. J. Zhang, "Efficient cooperative spectrum sensing with minimum overhead in cognitive radio," IEEE Transactions on Wireless Communications, vol. 9, no. 10, pp. 3006 –3011, October 2010.
[27]. P. Kaligineedi and V. K. Bhargava, "Distributed detection of primary signals in fading channels for cognitive radio networks," in Proceedings IEEE GLOBECOM 2008, pp. 1-5, 2008.
[28]. S. Chaudhari, J. Lunden, V. Koivunen, and H. V. Poor, "Cooperative sensing with imperfect reporting channels: Hard decisions or soft decisions?," IEEE Transactions on Signal Processing, vol. 60, no. 1, pp. 18 –28, January 2012.
[29]. J. Ma, G. Zhao, and Y. G. Li, "Soft combination and detection for cooperative spectrum sensing in cognitive radio networks," IEEE Transactions on Wireless Communications, vol. 7, no. 11, pp. 4502–4507, November 2008.
[30]. Z. Quan, S. Cui, and A. H. Sayed, "Optimal linear cooperation for spectrum sensing in cognitive radio networks," IEEE Journal of Selected Topics in Signal Processing, vol. 2, no. 1, pp. 28-40, February 2008.
[31]. Y.-D. Yao and A. U. H. Sheikh, "Outage probability analysis for microcell mobile radio systems with cochannel interferers in Rician/Rayleigh fading environment", Electronics Letters, vol. 26, no. 13, pp. 864-866, June 1990.
[32]. E. Blossom, "Exploring GNU Radio", Available online at: http://www.gnu.org.
[33]. Ettus Research LLC, "Universal Software Radio Peripheral 2", Available online at: http://www.ettus.com.